California Creepmeters

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Investigations

1. Monitoring program. Creepmeters are operated on faults in California to complement creepmeter arrays operated by the USGS. Data from 13 locations are collected during visits scheduled 3-4 times each year. Two instruments operate south of the Loma Prieta aftershock zone, five are operated in the Parkfield region (2 utilizing USGS telemetry), one on the Eureka Peak fault south of Landers, and two on the southern San Andreas fault at Indio and Durmid Hill. Continuous recording creepmeters are also operated on the San Jacinto fault at Anza, and two on the Superstition Hills fault, together with two manual observing sites. One of the Superstition installations is a differential creepmeter [*Bilham and Behr, 1992*]. Approximately 10 additional temporary sites have been operated during the last few years during afterslip investigations.

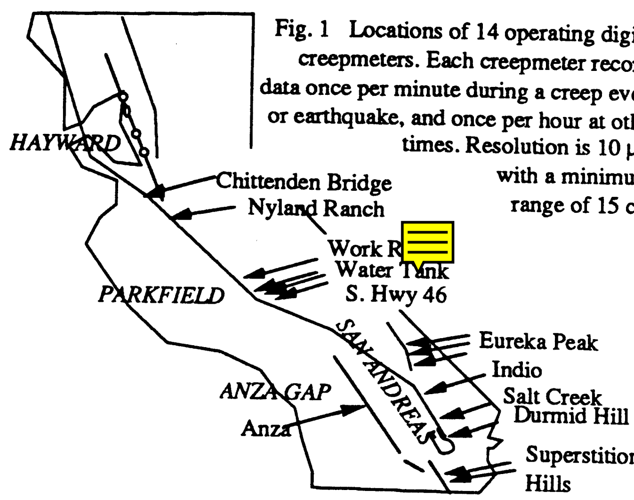

Fig. 1 Locations of 14 operating digital creepmeters. Each creepmeter records data once per minute during a creep event or earthquake, and once per hour at other times. Resolution is 10 µm with a minimum range of 15 cm.

Creepmeter	*location*	*sensor*	*length*
Work Ranch	Parkfield	15 cm caliper	10 m
Water Tank	Parkfield	15 cm caliper	18 m
South HW46	Parkfield	15 cm caliper	8 m
Classen Ranch	Parkfield	10 cm LVDT+caliper	20 m
Varian	Parkfield	1 m magnetostrictive	20 m
Indio	southern San Andreas	15 cm caliper	18 m
Durmid Hill	southern San Andreas	15 cm caliper	8 m
Anza	San Jacinto fault	50 cm caliper	10 m
Site zero	Superstition Hills fault	15 cm caliper	8 m
Site 1	Superstition Hills fault	2 x 15 cm caliper	2*8 m
Site 2 (manual)	Superstition Hills fault	15 cm caliper	8 m
Site 3(manual)	Superstition Hills fault	15 cm caliper	8 m
Nyland Ranch	San Andreas San Juan Bautista	15 cm caliper	8 m
Chittenden Bridge	San Andreas Pajaro River	15 cm caliper	136 m
San Andreas Rd	Eureka Peak Fault (discontinued)	15 cm caliper	8 m
Pueblo Rd	Eureka Peak Fault	15 cm caliper	12 m
Juarez Rd	Eureka Peak Fault (discontinued)	15 cm caliper	8 m
Salt Creek	southern San Andreas	5 cm LVDT	10m

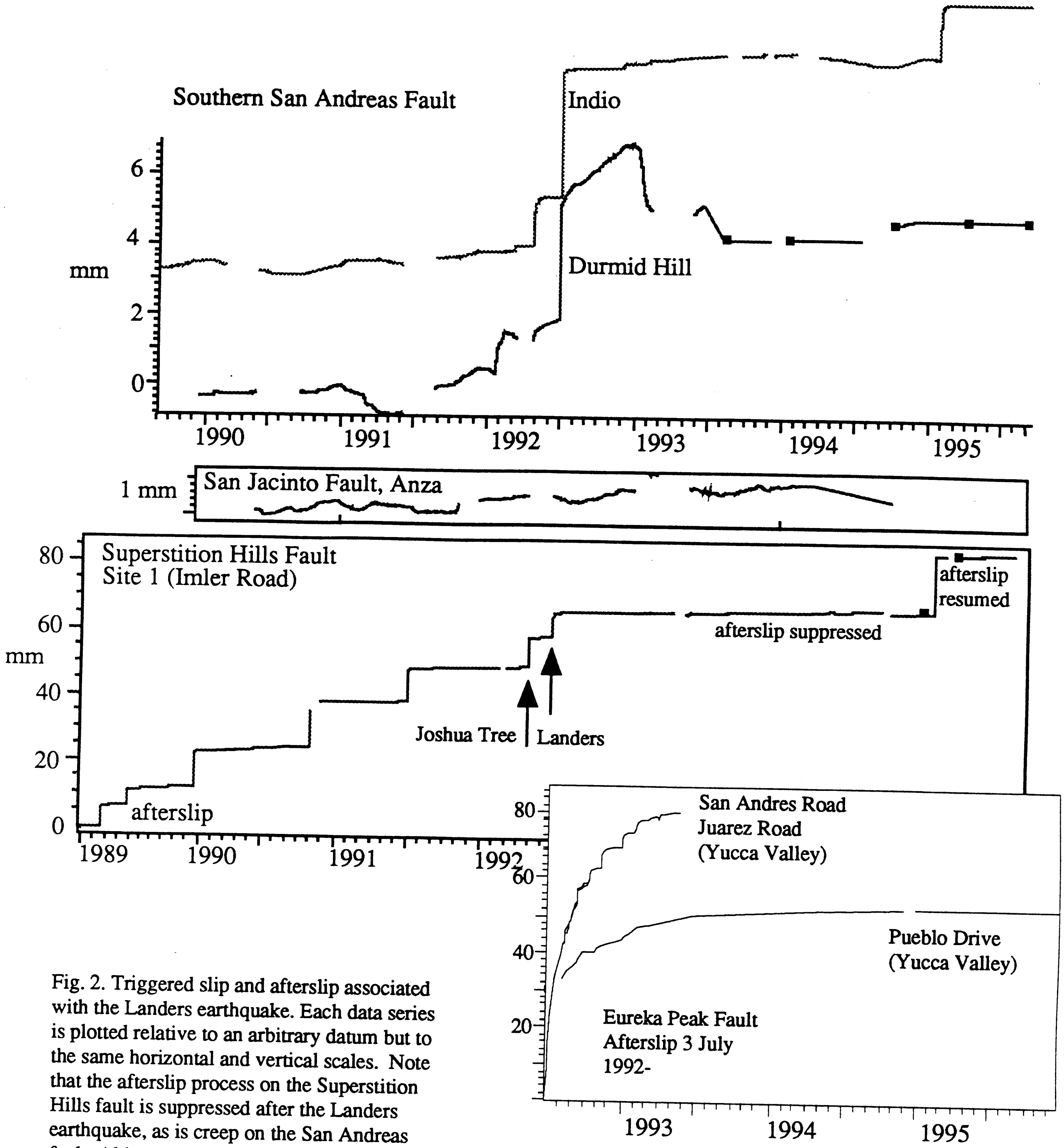

Fig. 2. Triggered slip and afterslip associated with the Landers earthquake. Each data series is plotted relative to an arbitrary datum but to the same horizontal and vertical scales. Note that the afterslip process on the Superstition Hills fault is suppressed after the Landers earthquake, as is creep on the San Andreas fault. Although no appreciable creep is observed by our creepmeters prior to the Landers events Louie et al. 1988 indicate creep rates of 2-6 mm/year in the decade preceding these data. The surface San Jacinto fault at Anza is evidently locked (±1 mm). Creep at Pueblo Drive Nov 94- Nov 95 has been less than a few mm. Squares indicate caliper readings of slip.

Results

1. Creep hesitation in southern California following Landers events

The long-period rate of decay of slip on the Superstition Hills fault has been determined by *Wennerberg and Sharp* (Eos. Trans Am. Geophys. Un., 74, 195, 1993) to obey a modified form of the decay curve proposed by *Marone et al* .(1991). Thus the mean creep rate until mid 1992 was entirely predictable. A 1992 creep event was followed within 6 weeks by a creep event triggered by the Landers earthquake, which also triggered slip on the southern San Andreas fault [*Bilham et al. 1992; Bodin et al. 1993*]. Slip triggered on the Superstition Hills fault did not exceed that expected from the long-period afterslip decay rate, however, no creep events occurred in the following 2.5 years, an interval twice as long as any hitherto. This interval was terminated by a single large event in January 1995 with slip exceeding 12 mm at approximately the same time as a creep event on the San Andreas fault at Indio (Figure 2). Creep has not occurred on the southern San Andreas fault at Durmid Hill since the Landers sequence. The 3 mm/year uplift of Durmid hill noted by Sylvester et al. (1993) ceased following the Landers sequence (Sylvester, personal communication 1994).

How are we to interpret the reduction in creep rate on the San Andreas fault in the Coachella Valley and on the Superstition Hills fault following the Landers event? Model simulations of stress changes accompanying Landers require small increases in fault-normal compression and along-strike dextral shear at these locations (Table 1). Given that a ubiquitous decrease in dextral slip rate has occurred the observed effects must be either the result of the calculated small increment in compressive stress clamping the fault, or the inferred change must be in error due to an incorrect assumption about the overall stress changes during the Landers sequence.

Table 1 Stress changes resulting from Landers sequence (Simpson, personal communication, 1994)

location	Imler Rd., Superstition Hills	Indio, San Andreas	Durmid Hill San Andrea
along-fault stress (bars)	0.028 dextral	0.416 dextral	0.0902 dextral
fault-normal stress (bars)	0.022 compression	0.492 compression	0.063 compression

The interruption in uplift at Durmid Hill suggests that current models for compression there may be in error. Moreover, the inferred increment in compressive stress appears too weak to clamp the surface fault. We thus suspect that the coseismic strain changes modeled by various investigators form an incomplete description of the actual strain changes that have occurred in southern California since mid 1992.

2. Post Landers mainshock afterslip on the Eureka Peak Fault

Afterslip on the Eureka Peak Fault in the suburbs of Yucca Valley [*Behr et al., 1994*] has reduced to levels close to the noise (<3mm/year)). Vandalism and theft have resulted in the loss of 3 instruments in the region and we now maintain only one creepmeter near the northern end of the fault. The region near the Pinto Mountain fault remains a clear slip deficit in the context of a throughgoing link between the 1992 Landers and Joshua Tree events. Afterslip has reduced to less than a few mm/year with a total cumulative offset of the order of 20 cm near the center of the fault.

3. San Jacinto fault at Anza

No creep events have occurred at this site since installation in January 1990. Cumulative dextral slip is less than 1.5 mm in 5 years. The data show irregular expansion and contraction of less than 0.3 mm/year across the fault (Figure 1).

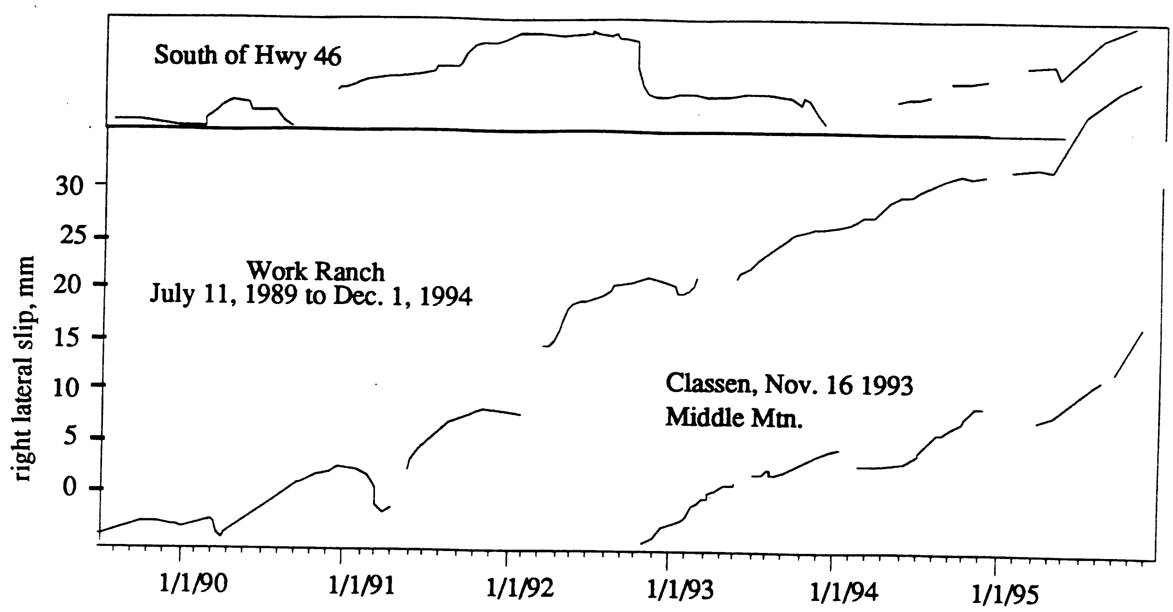

Fig. 3. Data from three of the Parkfield creepmeters since their installation. The time series have the same vertical and horizontal scales and are indexed to an arbitrary datum. The left-lateral purturbations on the signals are attributed to the effects of rainfall and thermal expansion of soils.

4. San Andreas fault at Parkfield (Figure3)

Our digital creepmeters supplement the USGS creepmeter array at each end of the Parkfield region. The instruments are designed to monitor coseismic slip and afterslip creep rates. Two creepmeters operate near the center of the fault. No M≈6 earthquake has yet occurred.

5. Post Loma Prieta creep at Nyland Ranch- Inferred San Andreas slip deficit 3.5 m.

Afterslip continues at Nyland Ranch (Behr et al. 1995 and Figure 4). Bodin and Bilham (1994) calculate that the San Andreas surface fault at this site has a surface slip deficit since 1800 that now exceeds 3.5 m. This slip deficit apparently decreases to 2 m near the Loma Prieta rupture.

6. Upgraded creepmeters

A program to upgrade southern California creepmeters operated by Caltech has been initiated. We have started by improving the transducing system on the Salt Creek instrument (80 degrees to the fault) with an LVDT sensor and temperature measurements. Approximately a year of data from this instrument is shown in Figure 5. After correction for direct thermal effects a residual thermoelastic signal in the ground remains which we shall attempt to further suppress use in time series prediction methods. The daily-weekly thermal noise in the system is evidently less than 0.3 mm at present.

7. Creepmeters on the Hayward fault

We have installed 4 permanent creepmeters on the Hayward fault. These use considerably enhanced installation methods and transducing principles compared to those described in this report. The end attachement points consist of 10-30 m deep drilled assemblies. An essentially isothermal length standard has been introduced which does not contact the end attachment points, and the sensors are entirely LVDT systems with in situ calibration and parallel manual reading systems. See USGS report for grant 1434-93-G2308.

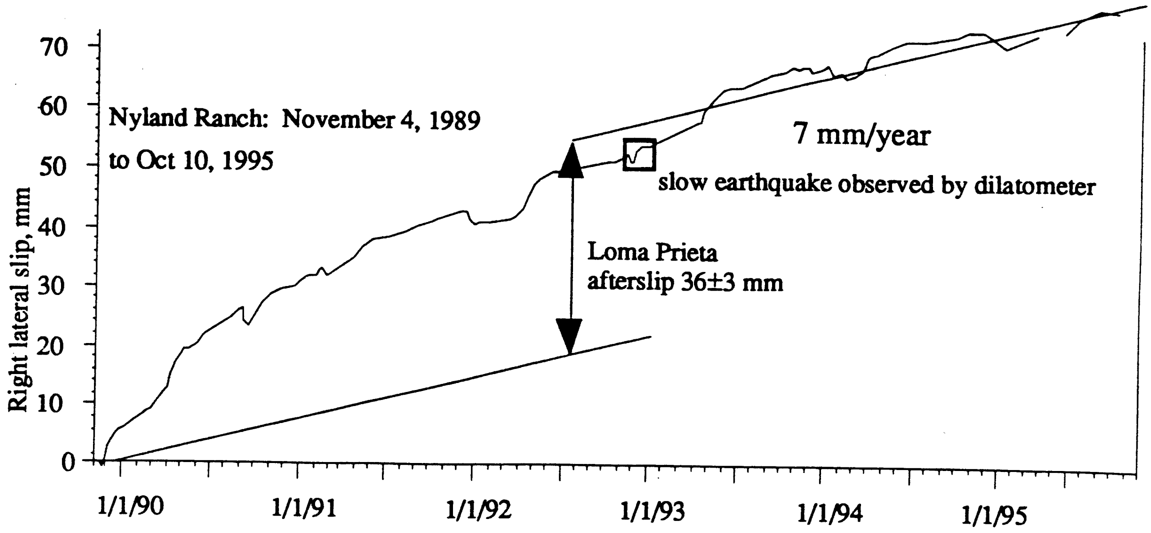

Fig.4. The mean creep rate of 7 mm at Nyland Ranch observed between 1968 and 1989 was re-established in early 1993 following approximately 35 mm of Loma Prieta afterslip. We calculate that up to 3.5 m of slip is overdue near this location based on the absence of significant seismicity since 1800. A slow earthquake with perhaps 5 cm of slip is inferred to have occurred at the time indicated by the box, and although this was accompanied by no simultaneous surface slip, it will be noted that the 1989-1992 surface slip of 5 cm is equivalent to this intermediate depth slow slip event.

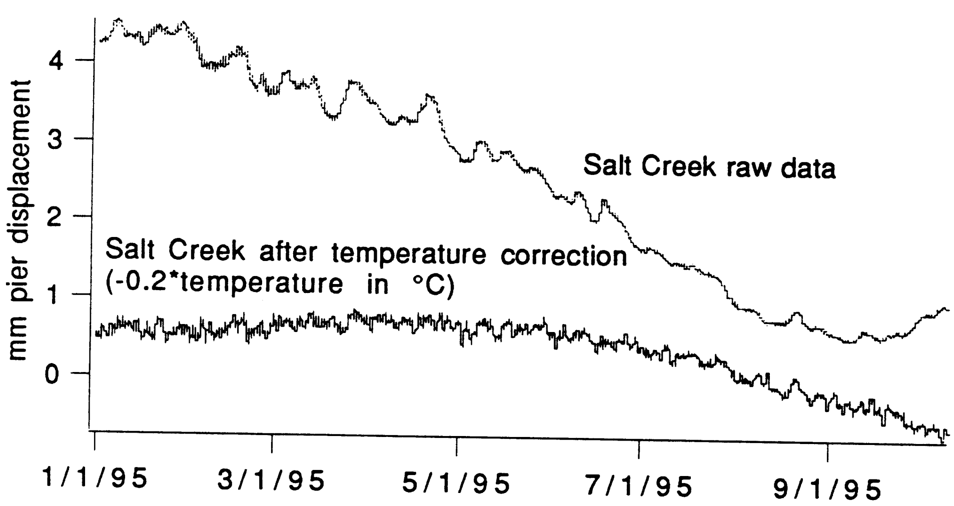

Fig. 16 Raw creep and temperature-corrected creep data from Salt Creek (Durmid Hill, southern San Andreas Fault). Neither this creepmeter nor our creepmeter 4 km to the south have recorded creep since the Landers earthquake.

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